Project Title: Near Fault Directivity Pulse Model: Development and Application in Scenario and Probabilistic Maps of Pulse Parameters in the San Francisco Bay Area

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Investigations Undertaken

The objective of this study is to develop an improved representation of near-fault ground motions for use in building codes. The effects of rupture directivity on near-fault ground motions have been recognized by strong-motion seismologists for several decades. The propagation of fault rupture toward a site at a velocity close to the shear wave velocity causes most of the seismic energy from the rupture to arrive in a single large long-period pulse of motion that occurs at the beginning of the record (Somerville et al., 1997). This pulse of motion, sometimes referred to as "fling," represents the cumulative effect of almost all of the seismic radiation from the fault. The radiation pattern of the shear dislocation on the fault causes this large pulse of motion to be oriented in the direction perpendicular to the fault, causing the strike-normal peak velocity to be larger than the strike-parallel peak velocity.

Currently, all seismic design guidelines and codes specify design ground motions using the response spectrum. However, there is a growing recognition that the response spectrum alone does not provide an adequate characterization of near-fault ground motions. This is because near fault ground motions are characterized by a relatively simple long period pulse of strong motion having relatively brief duration, rather than by a stochastic process having relatively long duration that characterizes more distant ground motion. Unlike the case for more distant ground motion, the resonance phenomenon that the response spectrum is designed to represent has insufficient time to build up when the input is a near-fault pulse. The response spectrum is thus not capable of adequately describing the seismic demands presented by a near-fault pulse. Current trends in the development of future building codes have all embraced the concept of performance based design. The goal of performance based design depends on realistic specification of ground motion inputs and realistic models of building response. The ground motion input may need to be a time history instead of a response spectrum to adequately characterize nonlinear response to near-fault ground motions.

The principal objective of this study is to develop an improved method for the engineering specification of near-fault ground motions. In addition to the response spectrum, we would like to include time domain parameters that describe the near-fault pulse, such as its period, amplitude, and number of half-cycles. We have developed a preliminary model that relates time domain parameters of the near-fault ground motion pulse to the earthquake magnitude and distance. The model is for forward rupture directivity conditions, which produce a strong pulse of motion in the fault-normal direction. The pulse parameters that we have modeled are the period and peak amplitude of the largest cycle of motion of the velocity pulse. The records analyzed include 15 time histories recorded in the distance range of 0 to 10 km from earthquakes in the magnitude range of 6.2 to 7.3, augmented by 12 simulated time histories that span the distance range of 3 to 10 km and the magnitude range of 6.5 to 7.5.

Results

We have developed a preliminary model that relates time domain parameters of the near-fault ground motion pulse to the earthquake magnitude. The model is for forward rupture directivity conditions, which produce a strong pulse of motion in the fault-normal direction. The pulse parameters that we have modeled are the period and amplitude of the largest cycle of motion of the velocity pulse. The records analyzed include 15 time histories recorded in the distance range of 0 to 10 km from earthquakes in the magnitude range of 6.2 to 7.3, listed in Table 1. These recorded pulses are augmented by 12 simulated time histories that span the distance range of 3 to 10 km and the magnitude range of 6.5 to 7.5. All of the time histories are for soil site conditions, although in some cases rock time histories were spectrally modified to reproduce soil site conditions.

The preliminary relationship between the period T of the near-fault fault-normal forward directivity pulse recorded on soil and the moment magnitude M_w, assuming the period to be independent of distance, is:

$$\log10\ T = -2.5 + 0.425\ M_w$$

Constraining the relation between pulse period and magnitude to be self-similar, i.e. to grow in proportion to the fault dimension, we obtain the relation shown in Figure 1:

$$\log10\ T = -3.0 + 0.5\ M_w$$

This relationship was also examined for separate sets of recorded and simulated time histories. It was found that the period of the recorded time histories grows more rapidly with magnitude than that of the simulated time histories. However, when the recorded and simulated time histories were combined, the resulting relationship was very similar to that of the recorded time histories.

An approximate relationship between the peak velocity PGV on soil of the near-fault fault-normal forward directivity pulse and the moment magnitude M_w and closest distance R is:

$$\log10\ PGV = -1.0 + 0.5\ M_w - 0.5\ \log10\ R$$

This model assumes a linear relationship between PGV and R which may not be realistic at very close distances; data recorded at distances of less than 3 km were not used in developing this relationship. This relationship was also examined for separate sets of recorded and simulated time histories. It was found that the peak velocity of the recorded time histories grows more rapidly with magnitude than for the simulated time histories, and decreases more gradually with distance than for simulated time histories. The approximate model given above is based on the recorded time histories and a subset of the simulated time histories that is most compatible with the recorded time histories. This subset consists of simulations for the magnitude range of 6.5 to 7.0 containing strong forward rupture directivity effects.

It is expected that the period of the pulse is most strongly influenced by the rise time T_R of slip on the fault, which measures the duration of slip at a single point on the fault. Somerville et al. (1999) found a self-similar relation between rise time and magnitude from an empirical analysis of 15 crustal earthquakes:

$$\log10\ T_R = -3.34 + 0.5\ M_w$$

The self-similar relation between pulse period and magnitude obtained above is:

$$\log10\ T = -3.0 + 0.5\ M_w$$

Eliminating M_w from these two equations, we find that the period T of the pulse is related to the rise time T_R by the relation:

$$T = 2.2\ T_R$$

The period of the pulse is thus equal to about twice the rise time of slip on the fault. This is consistent with the fact that the rise time is a lower bound on the period of the pulse. If the fault were a point source, then the only source parameter that would contribute to the period of the pulse would be the rise time, and the period of the pulse would equal the rise time if wave propagation effects such as Q are ignored. Since the fault is actually finite, and the rupture velocity is less than the shear wave velocity, the finite apparent duration of the rupture as observed at recording stations also contributes to the widening of the pulse. For stations that experience forward rupture directivity, this apparent duration is much shorter than the actual duration of rupture.

We will use the pulse parameter prediction model described above to map the near-fault ground motion parameters. The procedure will be checked by comparing the maps made using the model with maps derived directly from time history simulations. The effects of rupture directivity are fully contained in the broadband simulation approach that we are using (Somerville et al. (1995), so the pulse parameters of the scenario maps can be derived directly from the broadband simulations of the scenario events. The pulse model allows us to readily generate maps for multiple scenario earthquakes, which will facilitate the generation of probabilistic maps of pulse parameters of near-fault ground motions.

Non-Technical Summary

Current trends in the development of future building codes have all embraced the concept of performance based design. The goal of performance based design depends on realistic specification of ground motion inputs and realistic models of building response. This input may need to be a time history instead of a response spectrum to adequately characterize nonlinear response. This is particularly true of near fault ground motions, which are characterized by a relatively simple long period pulse of strong motion having relatively brief duration, rather than by a stochastic process having relatively long duration that characterizes more distant ground motion which the response spectrum is designed to represent. The principal objective of this study is to develop an improved method for the engineering specification of near-fault ground motions. In addition to the response spectrum, we include time domain parameters that describe the near-fault pulse, such as its period, amplitude, and number of half-cycles. We have developed a preliminary model that relates time domain parameters of the near-fault ground motion pulse to the earthquake magnitude and distance. The model is for forward rupture directivity conditions, which produce a strong pulse of motion in the fault-normal direction. The pulse parameters that we have modeled are the period and peak amplitude of the largest cycle of motion of the velocity pulse.

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Table 1. Recorded Near-Fault Time Histories Used to Develop Pulse Model

Earthquake	Station	M	R	Directivity	Site Condition	
Landers	Lucerne	7.3	1.1	forward	mod to soil	rock
Loma Prieta	LGPC	7.0	3.5	forward	mod to soil	rock
	Lexington		6.3	forward	mod to soil	rock
Kobe	JMA	6.9	3.4	forward	mod to soil	rock
	Takatori		4.3	forward	soft soil	
	Port Island		6.6	forward	soft soil	
Northridge	Rinaldi	6.7	7.5	forward	soil	
	Olive View		6.4	forward	soil	
	Newhall		7.1	forward	soil	
	Sepulveda		8.9	forward	soil	
Erzincan	Erzincan	6.7	2.0	forward	soil	
I.V. 1979	Array 5	6.5	4.1	forward	soil	
	Array 6		1.2	forward	soil	
Morgan Hill	Anderson D	6.2	4.5	forward	soil	
	Coyote L D		0.1	forward	mod to soil	rock

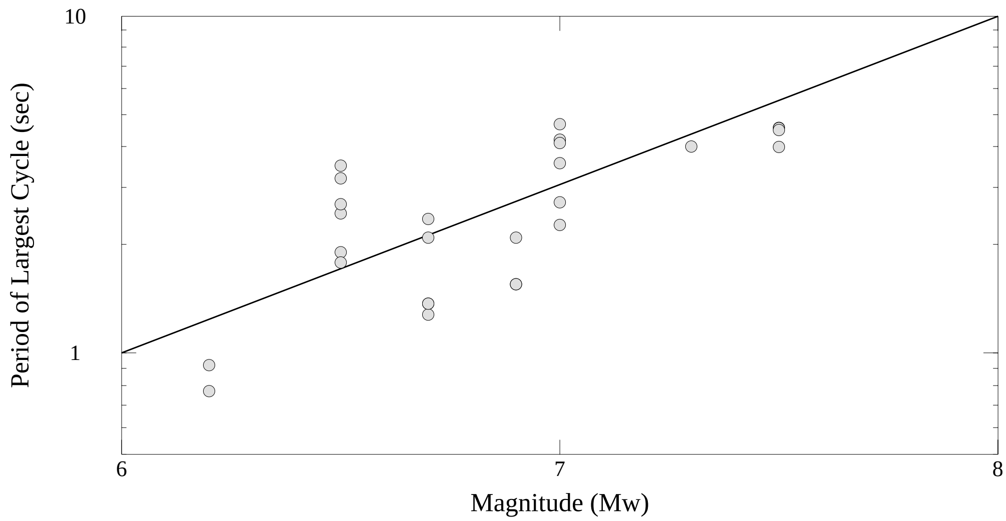

Figure 1. Relation between period of fault normal pulse and Mw for forward directivity